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ESTIMATING PERCENTILES OF NONNORMAL ANTHROPOMETRIC POPULATIONS.(U)

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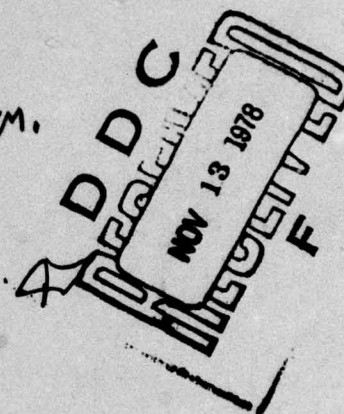
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By

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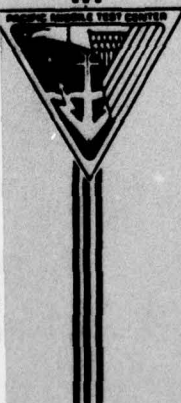
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cont. not make or require any assumption about the statistical distribution of the underlying population. Thus, the method can be applied to any population of anthropometric data, regardless of the normality of the data. The method is simple to use; however, a single nonlinear equation must be numerically solved on a computer by any one of numerous well-documented nonlinear root finding methods.

Two examples are used to illustrate the method. In the first example, selected samples of size 50 of hip breadth data are randomly drawn from a population of size 2420 observations from the 1967 anthropometric survey of U.S. Air Force flying personnel. The proposed method is compared to the standard gaussian method. Since this population was selected as normally distributed, the standard method outperforms the proposed nonparametric method. In the case of grip-strength data, the proposed method yields more accurate estimates, in a mean squared error sense, of the upper percentiles of this population. For anthropometric distributions known to be nonnormal or where normality cannot be assumed, the proposed nonparametric method appears a method for consideration.

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ESTIMATING PERCENTILES OF NONNORMAL ANTHROPOMETRIC POPULATIONS: FINAL REPORT

H. F. Martz, Jr.

ABSTRACT

The most commonly used method for estimating percentiles of anthropometric populations is based on the assumption that the population is normally distributed. This assumption is approximately true for many such variables, e.g., hip breadth. On the other hand, numerous nonnormally distributed anthropometric populations are known to exist, e.g., grip strength. The question of how to estimate percentiles of nonnormal populations is addressed here.

A nonparametric percentile estimation method, based on the use of a kernel-type probability density function estimator, is presented. A "nonparametric" method is defined as a method that does not make or require any assumption about the statistical distribution of the underlying population. Thus, the method can be applied to any population of anthropometric data, regardless of the normality of the data. The method is simple to use; however, a single nonlinear equation must be numerically solved on a computer by any one of numerous well-documented nonlinear root finding methods.

Two examples are used to illustrate the method. In the first example, selected samples of size 50 of hip breadth data are randomly drawn from a population of size 2420 observations from the 1967 anthropometric survey of U.S. Air Force flying personnel. The proposed method is compared to the standard gaussian method. Since this population was selected as normally distributed, the standard method outperforms the proposed nonparametric method. In the case of grip-strength data, the proposed method yields more accurate estimates, in a mean squared error sense, of the upper percentiles of this population. For anthropometric distributions known to be nonnormal or where normality cannot be assumed, the proposed nonparametric method appears a method for consideration.

INTRODUCTION

It is common practice to characterize anthropometric design limits in terms of suitable percentiles of a population of interest. A percentile gives the percentage of persons within the population who have a body dimension of a certain size or smaller. There are two commonly used methods for estimating percentiles. The first method is a simple well-known counting procedure. The data are arranged in ascending order of size, and then are grouped into convenient class intervals. Finally, the number of measurements below each upper class limit are counted, divided by the total number of measurements, and multiplied by 100 to determine the percentile rank. This method may be used either for the entire population or for a sample from the population. In the case of sample data, the computed percentile is an estimate of the (true) underlying population percentile. As a consequence, it is subject to certain statistical errors.

The second commonly used method is to assume that the anthropometric measurement of interest is normally distributed. The mean and variance of this distribution are then used in conjunction with stated "factors" to estimate the desired percentiles. The method requires that either the entire population of measurements is available or that the sample size is sufficiently large. The required "factors" are provided by Roebuck (1957), and a complete description may be found in the book by Roebuck, Kroemer, and Thomson (1975, pp. 132-144).

Most human factors investigators are aware of the existence of certain anthropometric populations which are nonnormally distributed. An example of such a population will be presented later. The question of how to estimate percentiles of such populations is an important one. The purpose of this paper is to present a method which can be used to obtain either population percentiles or percentile estimates for any anthropometric population. The method is a nonparametric one, which means that it does not assume specific knowledge of the statistical distribution, e.g., the normal distribution, of the measurement of interest. Thus, the method is particularly appropriate for use in populations which are either not known to be normal or known to be nonnormal.

METHOD

Background

Over the past two decades there have been some important developments in the area of statistical theory known as "nonparametric probability density function estimation." Wegman (1972a) presents a thorough summary survey of the historical developments in this area. In short, the basic idea is to provide an estimator which can be used to estimate the complete underlying probability density function, based on a sample from the population, without the necessity to first estimate certain "parameters"

of the population such as the mean, variance, etc. However, such characteristics may be estimated once the estimated probability density function has been obtained. Of particular interest here are the percentiles of such an estimated probability density function. The particular probability density function estimator considered here is attributed to Rosenblatt (1956) and Parzen (1962). Suppose that we have a random sample x_1, x_2, \dots, x_n of size n from some population having unknown and unspecified probability density function $f(x)$. Following Rosenblatt (1956) and Parzen (1962), the estimator of $f(x)$, $f_n(x)$, may in general be represented

$$f_n(x) = \frac{1}{nh} \sum_{i=1}^n K\left(\frac{x-x_i}{h}\right) \quad (1)$$

where $K(\cdot)$ is a suitably chosen function, referred to as the "kernel," "smoothing," or "window" function, and $h \equiv h(n)$ is a suitably chosen function of n in which it is required that $h \rightarrow 0$ and $nh \rightarrow \infty$ as $n \rightarrow \infty$. The kernel function K must also satisfy certain conditions which are given in Parzen (1962). Based on the work of Parzen (1962), Wegman (1972a, b), and Bennett (1970), the particular K and h given by

$$K(x) = 0.5 \exp(-|x|), \quad -\infty < x < \infty \quad (2)$$

and

$$h = sn^{-0.2}$$

where s is the sample standard deviation of the measurement x_1, \dots, x_n , are selected for use here. Although other functions could be considered, this choice is known to produce good results [Bennett (1970)]. Thus, the probability density function estimator to be used here is given by

$$f_n(x) = \frac{0.5}{nh} \sum_{i=1}^n \exp\left(-\left|\frac{x-x_i}{h}\right|\right) \quad -\infty < x < \infty \quad (3)$$

To better understand this estimator, figures 1 and 2 give a plot of (3) based on a random sample of size 100 observations from a symmetric (approximately gaussian) distribution and an asymmetric right-skewed distribution, respectively. Both $f(x)$ and $f_n(x)$ are shown for comparison, and arbitrary scales were chosen for x . It is observed in both cases that the estimates provide reasonably close approximations to the true densities.

Development

Of interest here are the percentiles of $f_n(x)$ given in (3), since these are the desired estimates of the population percentiles of $f(x)$. Let x_a represent the 100 (a)th percentile of $f_n(x)$ given in (3). That is, for a specified value of a , x_a satisfies the equation given by

$$\int_{-\infty}^{x_a} f_n(x) dx = a. \quad (4)$$

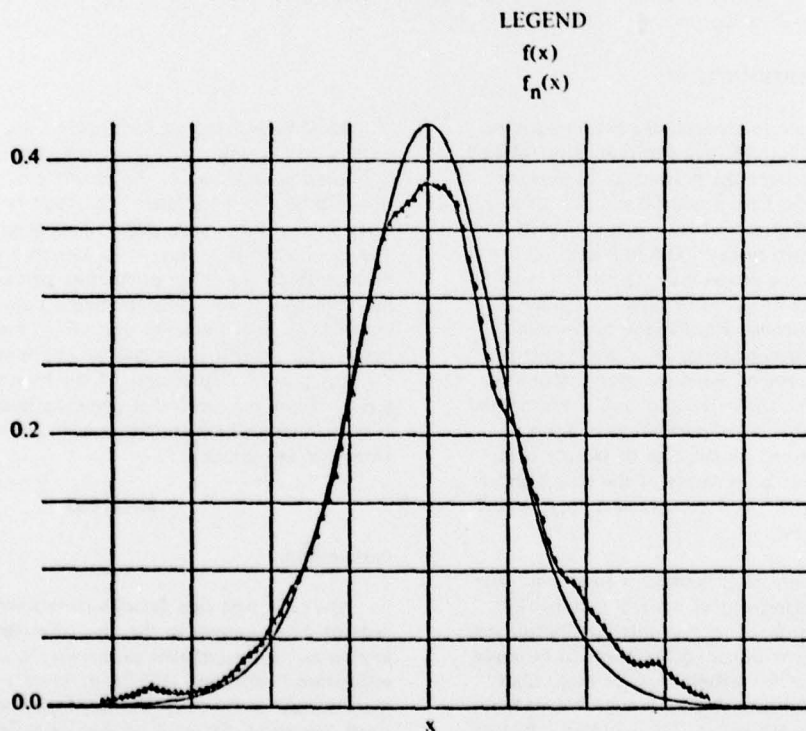


Figure 1. The Estimate $f_n(x)$ of an Underlying Gaussian Density $f(x)$.

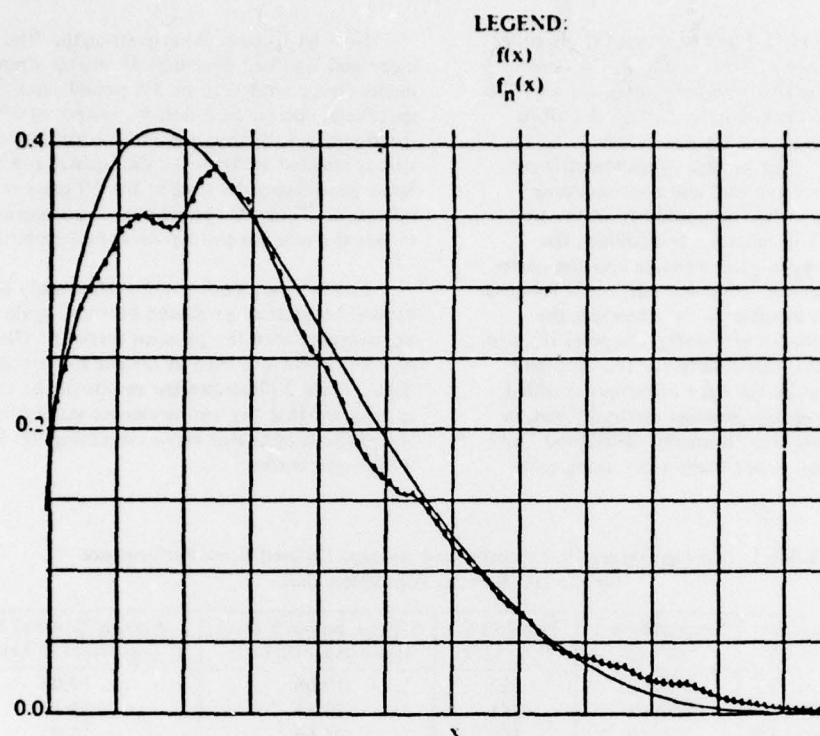


Figure 2. The Estimate $f_n(x)$ of an Underlying Right-Skewed Density $f(x)$.

Thus, x_a is the required percentile estimate of the population percentile value for which 100 (α) % of the anthropometric measurements do not exceed this value. For example, if $\alpha = 0.95$, then $x_{0.95}$ is the required estimate of the 95th population percentile.

Substituting (3) into (4), integrating, and simplifying gives x_a as the solution to the nonlinear equation given by

$$G(x_a) \equiv h \ln \left[\sum_{i=1}^n \exp(x_i/h) \right] - h \ln \left\{ \sum_{i=1}^n \exp \left(|x_i + x_a|/2h - |x_i - x_a|/2h - x_i/h \right) + \sum_{i=1}^n \exp \left(|x_i - x_a|/2h - |x_i + x_a|/2h + x_i/h - 2x_a \right) \right\} - x_a = 0. \quad (5)$$

Although this equation looks formidable, it may be easily and efficiently solved for x_a on a computer by means of any one of numerous well-documented nonlinear root finding subroutines.

EXAMPLES

The percentile estimation method presented here was

used to estimate selected percentiles for certain anthropometric variables in the survey of USAF flying personnel conducted by Clauser, Alexander, and Kennedy (1967). In this survey, 185 variables were finally selected and recorded for 2420 male pilots. Two of these anthropometric variables will be considered here, namely, hip breadth and grip strength.

First, let us consider hip breadth. The population mean and standard deviation of all hip breadth measurements are respectively computed to be 352 millimeter (mm) and 19 mm. Based on a random sample of 500 hip breadth measurements, the hypothesis of normality of this population is accepted by the chi-square, Kolmogorov-Smirnov, and Cramer-Von Mises goodness-of-fit tests at the 20 percent level of significance. Thus, this population will be considered to be "normally distributed."

Let us examine the performance of the percentile estimation method presented here and compare the performance with the gaussian percentile estimation method. Of course, the gaussian method is expected to yield superior results in this case which may be thought of as a worst case analysis for the alternative percentile estimation method presented here. The procedure was as follows: Ten successive random samples each of size 50 were drawn without replacement from the population of hip breadth measurements. The 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 97.5, 99, and 99.5th percentile estimates were computed for each sample by both the gaussian method [see Roebuck,

Kroemer, and Thomason (1975)] and equation (5). In order to compare the performance of both methods, the corresponding population percentiles were computed for all 2420 observations by means of the counting method described earlier. These population percentiles were taken to be the standard reference values. The average nonparametric percentile estimates, gaussian estimates, and corresponding population percentiles were then computed from the ten samples and are presented in table 1. In addition, the average squared error between each estimate and the corresponding population percentile value was computed for both methods and is also given in table 1. As observed, the gaussian method is superior for estimating the percentiles of the hip breadth population, particularly for the 70th and larger percentiles. This is the result of utilizing the added information of normality in the gaussian method when, in fact, the population is indeed a "normally distributed" one. Recall that this assumption is not made when using equation (5).

Now let us consider grip strength. The population mean and standard deviation of all grip strength measurements are computed to be 5.6 pounds and 7.6 pounds, respectively. Based on a random sample of 500 grip strength measurements, the hypothesis of normality of this population is rejected by both the chi-square, and Cramer-Von Mises goodness-of-fit tests at the 10 percent level of significance. Thus, this population is not normally distributed as was the case for the hip breadth distribution.

Let us now examine the performance of the percentile estimation method presented here and again compare the performance with the gaussian method. The same manner of comparison was used as for the hip breadth population data. Table 2 illustrates the results of the comparison. It is observed that the nonparametric estimator outperforms the gaussian estimator when estimating the 97.5, 99, and 99.5th percentiles.

Table 1. Average Percentile Estimates and Average Squared Error Performance for the Hip Breadth Population Data

Percentile	Gaussian Estimate	Nonparametric Estimate	Population Percentile	Average Squared Error (Gaussian Estimate)	Average Squared Error (Nonparametric Estimate)
50.0	354.79	354.78	352	19.08	19.03
55.0	357.15	357.17	354	22.11	22.17
60.0	359.54	359.59	356	25.66	25.94
65.0	362.01	362.19	359	23.38	24.32
70.0	364.62	364.94	362	22.53	24.70
75.0	367.43	368.01	365	23.22	26.37
80.0	370.58	371.72	367	32.17	42.77
85.0	374.22	376.19	371	32.31	51.90
90.0	378.84	381.94	376	33.66	67.13
95.0	385.65	390.15	385	32.31	66.63
97.5	391.55	397.36	392	38.33	75.86
99.0	398.42	406.15	402	59.12	79.65
99.5	403.11	412.09	408	76.38	88.61

Table 2. Average Percentile Estimates and Average Squared Error Performance for the Grip Strength Population Data

Percentile	Gaussian Estimate	Nonparametric Estimate	Population Percentile	Average Squared Error (Gaussian Estimate)	Average Squared Error (Nonparametric Estimate)
50.0	56.35	56.35	56	0.82	0.82
55.0	57.28	57.28	57	0.90	0.90
60.0	58.22	58.22	58	1.02	1.02
65.0	59.19	59.19	59	1.19	1.19
70.0	60.22	60.22	60	1.42	1.42
75.0	61.32	61.42	61	1.76	1.90
80.0	62.56	62.93	63	2.20	2.14
85.0	63.99	64.70	64	2.47	3.23
90.0	65.80	66.99	66	3.19	4.99
95.0	68.48	70.60	70	6.64	7.69
97.5	70.80	73.61	73	10.35	9.21
99.0	73.50	76.90	76	13.36	10.90
99.5	75.34	79.22	78	15.38	13.31

CONCLUSIONS

In conclusion, based on the limited comparison just described, it is conjectured that the nonparametric percentile estimator will outperform the gaussian estimator for nonnormal populations. Although extensively investigated, the degree of performance improvement appears to be proportional to the degree of nonnormality. Future effort needs to be directed toward an extensive Monte Carlo simulation for further examination of the proposed nonparametric percentile estimator.

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